Renewable Energy Village Power Systems for Remote and Impoverished Himalayan Villages in Nepal

Zahnd Alex,
Department of Mechanical Engineering Kathmandu University
P.O. Box 6250, Kathmandu, Nepal
azahnd@wlink.com.np

Dr. Haddix McKay Kimber
University of Montana and The ISIS Foundation, Missoula, Montana, 59801, USA
kimber@isis.bm

Dr. Richard Komp
Maine Solar Energy Association, 17 Rockwell Rd SE, Jonesport ME 04649 USA
sunwatt@juno.com

Abstract

1.6 - 2 billion people in developing countries live in dark homes, without access to electricity, and 2.4 billion rely on traditional biomass for their daily energy services, such as cooking, heating and lighting. Lack of electricity and heavy reliance on traditional biomass are hallmarks of poverty in developing countries, and women and children in particular suffer enormous health problems due to open fire places. The high migration and urbanization rates in developing countries will continue, forcing governments to focus more on urban energy service provision and extension. That widens the gap between poor and rich, highlighting the relationship between poverty and access to electricity further. Nepal, with the majority of its people living in difficult to access areas with no roads is a typical example of that. Belonging to the poorest and most undeveloped countries, the per capita electricity consumption is among the lowest in the world. The geographical remoteness, the harsh climatic conditions, low population density with minimal energy demand and low growth potential, are some of the reasons why rural electrification costs in Nepal are prohibitive and the isolated rural mountain villages in Nepal will not be reached within the foreseeable future through grid extensions alone.

Nepal is not rich in fossil fuel resources but it has plenty of renewable energy resources, in particular water that is running down from the vast Himalayan mountain ranges in over 6,000

rivers. With 300 sunny days a year, the sun's freely available solar energy can also be converted into electricity.

In some of the most remote Himalayan valleys in Nepal, among the poorest and most marginalized groups of people, some encouraging steps have been taken in regard to elementary rural village electrification. The local available, renewable energy resources have been tapped into, and through Remote Area Power Supply (RAPS) systems, miniscule amounts of power, in the "watt" range rather than "kilo-watt", has been generated for elementary rural village electrification. In this way several villages have been electrified, for lighting purposes only, through different types of village integrated solar photovoltaic systems and the smallest kinds of hydro power plants, called pico hydro. The lights considered most appropriate and sustainable are 1 watt energy consuming white light emitting diodes (WLED), providing a minimum, but just sufficient light output.

This paper aims to highlight the urgency for appropriate and sustainable elementary rural village electrification in Nepal, in order to create opportunities to bring light into the dark, smoke filled homes of the poorest of the poor. It discusses the possible, appropriate technologies, such as solar PV systems for single homes and whole villages, pico hydro power plants and small wind generators, for small scale rural village power generation schemes. It describes and discusses some of the implemented village solar PV and pico hydro power plant projects, including the experiences gained and the lessons learned.

Keywords: Rural Village Electrification, Renewable Energy Resources, Renewable Energy Technologies, RAPS System, Holistic Development, Lighting, Sustainability, Appropriate Technology

1. Introduction

Nepal is a landlocked country, with India to the south, east and west and the People's Republic of China to the north. It lies between 26° 22' to 30° 27' N latitude and 80° 04' to 88° 12' E longitude, with an altitudinal range from 60 m in the south to 8,848 m in the north. With its almost rectangular shape, Nepal encloses a total area of 147,181 km^2. The average north-south width is about 193 km and East-West length averages 885 km[1]. Broadly, Nepal lies within the subtropical monsoon climatic system, and has five different types of climates[2], from tropical in the south to alpine in the north due to its immense topographical variation.

80% - 85% of Nepal's 27.6 million people[3] live in rural areas, with about half so remote that the nearest road, and indeed the national grid, is within 2 - 16 days walking distance. The Humla district in the far north-west of Nepal, is where most of the rural village electrification projects related to in this paper take place (see map below). The GDP/capita (Gross Domestic Product) is 1,100 -1,370 US$[4], and the HDI (Human Development Index) is 0.499 for Nepal and 0.244 for the Humla district[5]. Around 40% of Nepal's people are living below the poverty line[6].

The average life expectancy in Nepal is 60.1 years for men and 59.5 years for women[7], though in rural and impoverished mountain areas such as Humla, the life expectancy is between 36 – 50 years[8], with the women on an average 2 years lower than men. That puts Nepal among the few countries where women have a lower life expectancy than men, indicating the enormous responsibilities, hardships and burdens they carry within their society, especially in the remote, undeveloped high altitude mountain regions. Nepal has an annual population growth of 2.27%, though in Kathmandu, Nepal's capital, it is 4.83%[9], showing the strong urbanization trend.

The national literacy rate is given with 45.2%, (62.7% of men able to read and write and 27.6% of the women[10]). Again the picture in the poor mountain regions is rather different. In Humla only 4.8% of the women are literate, and the average years of schooling is just 0.88 years[11].

The national average electricity consumption per capita in the 2003 - 2004 fiscal year was just under 70 kWh/year[12], placing Nepal among the lowest electricity consumers in the world.

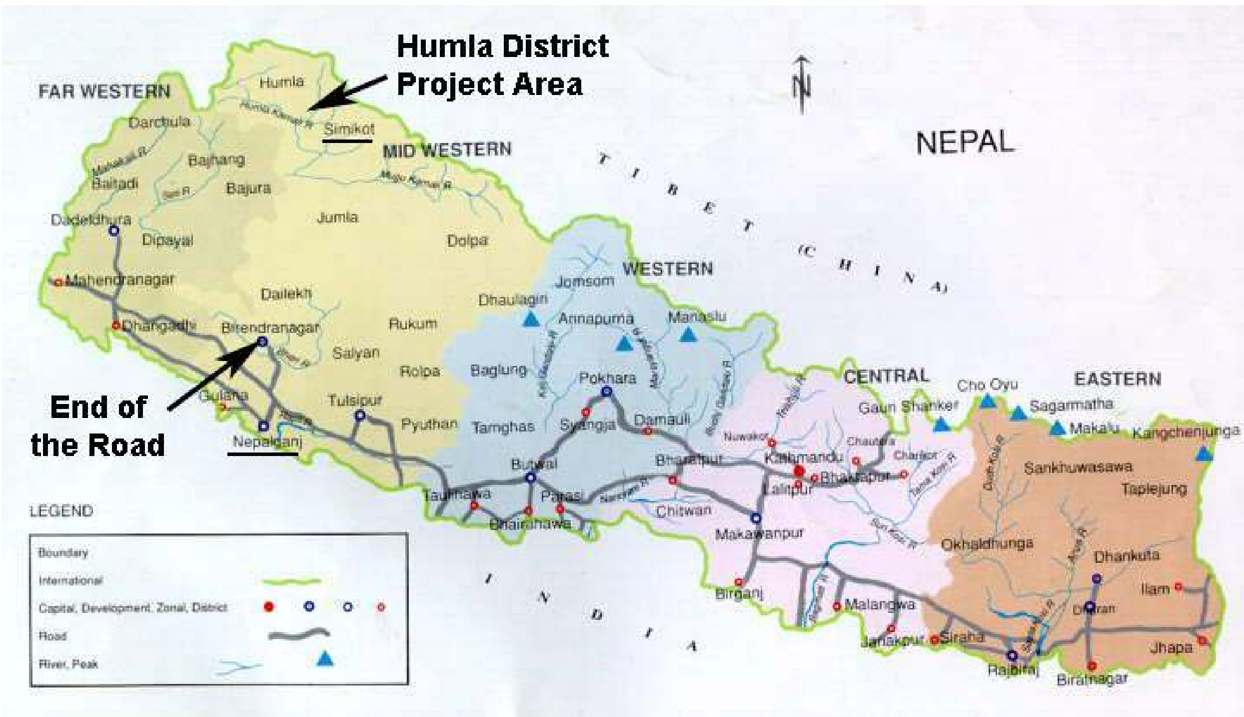


Figure 1: Nepal map (with author's adjustment). From the "End of the Road" one either has to walk 16 days to Simikot (Humla district), or take a one hour, adventurous airplane journey through the Himalayas from Nepalgunj (in the very south at the India boarder) to Simikot.

2. Nepal's Energy Scenario

Nepal is poor in fossil fuel resources, and thus has to import all its non-renewable energy resources, such as kerosene, diesel, petrol, liquefied petroleum gas (LPG) and coal, from its neighboring country, India. The prices for these fossil fuels are strongly dependent on the global economic and political conditions.

But what Nepal is rich in are renewable energy resources, such as biomass, water, sunshine and also wind in some particular areas. The great benefits of these energy resources are, that they are free and renewable, and therefore do not incur ongoing fuel costs. Further, a great advantage is that these renewable energy resources are locally available, and thus can be part of the local community's economy and lifestyle.

2.1. Nepal's Energy Resources and Their Use

2.1.1. Biomass

With still around 80% - 85% of the population living in rural areas, the primary energy source used to provide most of the necessary daily energy services in Nepal since centuries, has been fuel wood, often supplemented by crop residues and animal manure, dependent on the prevailing local customs, cast, altitude and geographical zone.

According to the Nepal Water and Energy Commission Secretariat (WECS), about 30% (or 42,054 km^2) is covered with forest. About 11% is covered with shrubs and bushes. Monitoring data shows that the forest areas are annually reduced by 1.7%[13]. Further, forest and shrub areas are increasingly converted to cultivated land. In 1999 about 15 million metric (MT) tons of air-dry fuel wood were consumed to provide the annual energy services. 98% of that total fuel wood consumption is used in private households. But the annual sustainable fuel wood production from all of Nepal's accessible forests amounts to only 7 MT[14].

Families in the remote areas of Nepal use precious trees as firewood for cooking, room heating and lighting. These activities, especially indoor cooking and lighting on open fire places, consume daily 20 kg – 40 kg firewood a day[15], with direct chronic impact on the health of women and children in particular, due to the enormous indoor smoke pollution. It is no surprise that they suffer from high rates of respiratory diseases, asthma, blindness and heart disease[16], resulting in the low life expectancy for women and the high death rate of children < 5 years of age[17].

The fuel wood consumption, through tree cutting, forest clearing and fuel wood collection, for the past twenty years, has been well above the rate of sustainable forest growth. Ever longer and more dangerous journeys for the women and young girls, of up to 7 hours a day[18] are now required to collect the necessary fuel wood. This has forced the local people to increasingly utilize agricultural residues to meet their growing energy demands. This in turn results in decreased crop productivity, increased soil erosion and arable land loss. Further, as Prof. Smith[19] shows, the burning of dung and agricultural residues on open cooking fires, produces up to three time more indoor pollution as burning fuel wood. Deforestation is widespread and the once picturesque, bio-diverse forests and valleys are stripped of their resources in unsustainable ways.

2.1.2. Hydro Power

Nepal is the major contributor to the Ganga Basin in the north of India. The annual discharge of out flowing rivers from Nepal to India is about 236 billion m^3 [20] from over 6,000 rivers, with many rivers losing a potential height of about 4,000 meters within a north – south distance of 100 km. This creates a theoretical hydropower potential of 83,290 MW[21]. The harsh terrain and difficult access to many areas limits the theoretically exploitable hydro power potential to a more realistic technically and economically profitable potential. Therefore, the realistic realizable, economically and technically feasible, hydropower potential has been estimated to be 42,130 MW[22]. With this figure, and an assumed capacity factor of 80% the annual energy potential of Nepal's rivers can be estimated to be around 300 TWh.

Figure 2: Some of the major rivers of Nepal, with that enormous north – south drop, from the 6,000 – 8,000 meter altitude of the Himalayan range to the north, to the flat southern part, which is just above sea level. Map from: http://www.mapsofworld.com/nepal/nepal-river-map.html

Since 2003 a total of 576 MW[23] rated power capacity, from 23 installed hydro power plants has thus far been realized. Thus, today a mere 1.37% of the technically and economically feasible hydro power potential of Nepal has been developed. During the 2003 – 2004 fiscal year the total annual energy generated was 2,381 GWh[24], which implies a capacity factor of just over 47%. With an national average electricity consumption per capita in the 2003 - 2004 fiscal year of just under 70 kWh/year[25], including the enormous energy loss of ~ 24%, accredited mainly to the large grid transmission line losses and power theft, compared to around 900 kWh/year[26] for most of the developing countries, puts Nepal among the lowest electricity consumers in the world.

Thus one can say that the "luxury" of having electricity available at the flick of a switch is still a dream for about 80%, or ~ 22 million people in Nepal. In the Nepal Electricity Authority's (NEA) long-term planning, 29 hydro power plants, with a total of 22,435 MW rated power output have been proposed for Nepal's future power development.

2.1.3. Solar Energy

Nepal lies in the ideal 30° North "solar belt"[27] with about 300 sunny days a year[28]. Solar irradiation measurements with pyranometers on tracking frames for solar PV modules in three different geographical locations in Nepal over the course of two years (2004 – 2005), showed that 1,950 – 2,100 kWh/year (with an average of 5.342 – 6.027 kWh/m^2 per day[29]) of solar irradiation had been intercepted. The extreme values were 3.5 kWh/m^2 per day on a rainy overcast monsoon day in July in Kathmandu, and 9.9 kWh/m^2 per day on a sunny late autumn day in November, in Simikot in Humla (at 3,000 m altitude). According to recent studies, the PM_{10} (Particulate Matter < 10 micrometers in diameter, and thus able to enter the respiratory system) values for Kathmandu during the day are as high as 495 µg/m^3 in core city areas, with TSP (Total Suspended Particulate) values up to 572 µg/m^3. Also 24-hour average values were as high as 225 µg/m^3 for PM_{10}, and 379 µg/m^3 for TSP respectively[30]. In contrast, the WHO guidelines provide maximum average 24-hours values of 70 µg/m^3 for PM_{10}, and 120 µg/m^3 for TSP. These high values in Kathmandu are mainly produced by the inefficient combustion of fossil fuels from vehicles and the local brick kiln industry. Days with thick smog layers over the Kathmandu valley, reducing the intensity of the solar irradiation by ~ 20% are not seldom. Considering this data[31] solar PV modules installed at an angle of 30° south (considered as the "Nepal standard"), can intercept 4.8 – 6.0 kWh/m^2 solar energy on a daily average in most of the places in Nepal[32].

Since 2002 the SWERA[33] (Solar and Wind Energy Resource Assessment) project under the leadership of NREL (National Renewable Energy Laboratory) in Golden Colorado USA, develops with the Tribhuvan University (Nepal's national university) and the Ministry of Science and Technology maps of the available solar resource in Nepal. Combined NASA satellite data with some measured ground data are presented in country maps with a 10 km grid for annual global horizontal, and at latitude tilt global solar irradiation. The maps and the actual ground measurement data recorded by the author at three different places agree within ≥ 10% - 15%.

NEA has installed as part of a French government development project in 1989 three solar PV array systems in three remote areas (30 kW_R in Kodari, 50 kW_R in Gamghadi and 50 kW_R in Simikot), out of which the last two are still considered to be operational in the latest NEA power development graphs and charts[34]. Since October 2003 the Gamghadi system has totally failed, leaving the people, who have had simple low power lighting in their homes for 14 years, again in the dark. The Simikot system (see picture below) provides since the late 90s only DC power (both the 5 kW and a 50 kW inverters failed due to lack of maintenance/repair funds, spare parts and skilled professionals). For ~ 100 households with each one to three 40 – 60 watt incandescent bulbs not connected to an on-off switch, only 1–2 hours per day indoor lighting is provided.

Picture 1[35]: Simikot Humla 50 kW_R Solar PV System, after 16 years of operation

While one has to recognize that 16 years of operation in such a remote area, with such an extreme and harsh climate, with minimal maintenance, better initial planning and budgeting would have enabled the system to continue to provide its valuable lighting energy services for probably another 5-10 years. These central solar PV systems though have prepared the way for the solar PV technology to have a good entry as an appropriate and sustainable technology, using the available local solar energy resource to generate energy, mainly for lighting purpose. NEA also installed over the years smaller solar PV systems for remotely-located mountain air strips for the civil aviation, for national telecommunication stations and some drinking water pumping systems in the lower flat areas, amounting to a total capacity of about 200 kW_R still operational.

In 2001 the government of Nepal, mainly through the financial support of the Danish government, established a solar PV home system (SHS) subsidy program[36]. That enables families living in the remote and poorer mountain regions, to install a SHS mainly for lighting (10 W_R – 40 W_R). Under that scheme, till the end of November 2005, a total of 61,892 SHS have been installed in 73 out of the 75 districts of Nepal, with a total peak power rating of 2,024.574 kW.

This growing demand for small scale SHS brought forth a mushrooming of solar energy companies in Nepal. While this is encouraging, not all companies have sound infrastructural and technical bases to provide quality products and after sales services. The latter in particular are very poor, as no subsidies are available for them. Therefore many systems once they are installed, are listed in the books and statistics, but are not followed up or properly maintained. Thus while the statistics look encouraging, with an appropriate renewable energy technology starting to make a difference in the lives of the poorest, the actual facts may show a very different picture[37].

A solar energy conversion technology more widely used and installed in urban areas is the solar water heater (SWH). The thermo-siphon SWH technology was transferred from Switzerland to Nepal in the early 70s and has now around 220 local Kathmandu based SWH manufacturers. Most of the locally manufactured SWHs are of the same old technology and size, as the focus was mainly on economic competitiveness among the fast growing number of manufacturers. The average local made SWH consists of a 2 x 2m^2 absorber with galvanized steel pipes and steel absorber fins. Each unit has a 150-200 liter warm/hot water storage tank, insulated with 50 mm glass wool. The overall efficiency [energy gained in the hot water (MJ) / incoming solar irradiation (MJ)] is low (~25%). Though there are no detailed figures of installed solar water heaters available, it is believed that between 50,000 – 80,000 units are operational in Nepal.

Since 2001 the Kathmandu University, under the main author's supervision, has been engaged in an applied research project for an improved SWH model for wider use. The research project focuses in particular on a locally manufactured high altitude SWH technology to run under freezing conditions, as a thermo-siphon system. A first unit for a high altitude village SWH bathing center, was installed in November 2005 in Simikot Humla (see picture below) and is at the moment of writing undergoing its first field tests during the cold winter months at an altitude of exactly 3,000 meter above sea level (9,843 feet). Once approved, it will be finally installed as part of a participatory holistic community development project in the village of Dhadhaphaya (see pictures 27 – 32, 39 – 46) in Humla, in Spring 2006.

Picture 2: First unit of the Nepali made High Altitude Thermo-Siphon SWH, with opened reflectors, designed to act as night time insulation, beside the ability to empty the absorbers and pipes. A horizontal and 40° fixed angle (same as the absorbers) pyranometer, allow the monitoring and recording of the actually received solar irradiation on the total absorber surface for exact efficiency calculations. The full size (4 units) of the High Altitude SWH bathing center system is designed to provide hot water for 1,100 people, for each to take a shower every two weeks.

Picture 3: The High Altitude Thermo-Siphon SWH in closed, or after sunset, position. The insulation all around the absorbers and the hot water storage tank consists of 100 mm polyurethane foam. Four thermocouples on one absorber measure the water temperatures at different heights, and 4 thermocouples, installed at different heights, measure the hot water storage tank temperature and stratification. All data is recorded every minute for the first 5 months of field tests during the winter of 2005/6. Initial efficiency calculations showed values of 45% - 55%.

2.1.4. Wind

Nepal is not very windy, as it is landlocked, and due to its unique geographical conditions, it has very few large flat areas of land. But there are various areas where rivers have cut deep north – south valleys into the massive Himalayan mountain range, stretching from the east to the west. Thus many valleys do have strong average winds blowing through them, and thus could enormously benefit from using their local wind energy resource (see Nepal relief map).

The joint SWERA project has not yet obtained sufficient wind resource data to create any national wind resource map. Thus the country's potential wind resource can still not be assessed sufficiently accurately, and therefore local available wind resources would need to be first evaluated/measured (time demanding and expensive) before a project can take place. Further, being directly related to the solar radiation and the local geographical, local wind conditions in regard to strength, continuity and direction, change very rapidly according.

Figure 3: Relief Map of Nepal shows some of the major deep north-south valley, creating a natural Venturi effect. Map: http://www.bugbog.com/maps/asia/nepal_map.html

With the huge water resource, a maturing hydro power industry, and increasing awareness and implementation of solar PV projects under governmental subsidy programs, it comes as no surprise that hardly any wind generation projects have been implemented in Nepal.

The few wind generator projects (known to the main author) can be summarized in the following:

1. A first 30 kW wind generator was funded by the Danish government and installed by NEA in 2001 in Kagbeni, Mustang district, which is a wind rich village at the bottom of the Annapurna valley, the world's "deepest valley" (see map above). But already after a few months a strong gust damaged the wind turbine's blades so badly that it was beyond repair.
2. In 2001 an imported Synergy S5000DD wind turbine was installed as part of a small hybrid (750 W_R solar PV array and wind turbine) system as power generation for a high altitude rescue clinic for alpinists, in the Mt. Everest region in the village of Pheriche. Apart from the installation the local industry and community had no part and benefit from it.
3. ITDG installed six small scale wind home systems with battery charging across Nepal. Emphasis was given to local manufacturing, and to train some local people. While this is the right approach to develop a future local manufacturing industry, no feedback or news has been made available on the outcome or results of the project.
4. The main author has himself installed a self-made small wind turbine with 180 W_R output power in 1998, and run it for 4 years in the remote area of Jumla, north west Nepal (http://www.lichtinnepal.ch.vu/). While that wind turbine was running without any failure for 4 years, generating small amounts of energy, just enough to charge the batteries for one home, the actual installation place was not ideal.
5. Since 2004, the KUPEG (at: http://ku.edu.np/~kupeg/reserch/reserch3.html), started a small scale wind turbine design and manufacturing project under the guidance of Dr. Peter Freere. Appling locally available technologies, equipment and resources, along side the training of local craftsmen, are part of the strategies.

These examples show that the application of small scale wind turbines for rural village electrification in Nepal is still very much in its infancy and that no project has thus far made headlines.

2.2. Nepal's Energy Consumption Pattern

Interesting trends can be seen in the following table (Figure 4), showing the energy consumption pattern and growth for Nepal's non-renewable and renewable biogas and micro hydro energy resources over the years 1990 – 2002, presented in TJ (or 10^{12} watt).

Fueltype	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Traditional	**232727**	**237614**	**242604**	**247699**	**252901**	**258212**	**263634**	**267138**	**272893**	**278748**	**284735**	**290859**	**298208**
Fuelwood	207887	212253	216710	221261	225907	230651	235494	237555	242687	247884	253199	258636	264985
Agri Residue	9332	9528	9728	9932	10141	10354	10571	11645	11893	12166	12446	12732	13148
Animal Dung	15508	15833	16166	16506	16853	17207	17569	17938	18313	18698	19090	19491	20076
Commercial	**10095**	**14830**	**17848**	**18322**	**20580**	**24784**	**27759**	**29441**	**32740**	**34576**	**44515**	**46701**	**49826**
Petroleum	7899	10933	13040	14842	16679	19119	21615	23623	26619	28180	30224	31286	32317
LPG	0	197	281	379	481	643	916	1075	1131	1232	1508	1975	2401
Motor Spirit	601	822	897	968	1040	1172	1380	1497	1572	1674	1862	1984	2119
Air Turbine Fuel	332	687	878	1039	1094	1357	1469	1731	1860	2009	2056	2283	1716
Kerosene	3129	3544	4437	5206	5877	6559	7568	8841	10226	10696	12006	11472	14018
High Speed Diesel	3752	5142	6196	6724	7436	8597	9501	9783	11402	11978	11780	12367	10857
Light Diesel Oil	87	119	100	60	117	149	174	78	38	21	156	134	94
Fuel Oil	0	253	86	280	424	406	341	320	54	189	428	482	569
Others	0	168	165	186	209	236	266	299	337	380	428	482	543
Coal	307	1777	2461	1090	1359	2839	3085	2540	2579	2618	10064	10803	12355
Electricity	1889	2120	2347	2390	2542	2826	3059	3278	3542	3778	4227	4612	5154
Renewables	**160**	**178**	**221**	**249**	**251**	**339**	**455**	**631**	**897**	**1061**	**1236**	**1454**	**1678**
Biogas	128	144	185	212	212	298	412	536	678	826	981	1179	1327
Micro Hydro	32	34	36	37	39	41	43	46	48	51	56	60	62
Solar	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	0	0	0	0	0	0	0	49	171	184	199	215	289
Total	**242982**	**252622**	**260673**	**266270**	**273732**	**283335**	**291848**	**297210**	**306530**	**314385**	**330486**	**339014**	**349712**

Figure 4: National Energy Consumption data for Nepal 1990-2002 (WECS Data-2, Chapter 3: Rural Energy-Pressure, State, Impacts and Responses; http://www.mope.gov.np/environment/pdf/state/chapter3.pdf)

While in 1990 the traditional fuels still made up 96% of the total annual energy consumption, in 2002 they are still providing 86% of all energy services. In actual mass the consumption increased by 27.5%, while Nepal's forests shrunk over the monitored time period by ~ 22%. The per capita traditional fuel consumption decreased from 1,072 kg per year in 1990 (with a population of 18.1 million and an assumed mixed traditional fuel energy value of 12 MJ/kg) to 987 kg (or – 8%). This, resulting from the sharp increased consumption of imported petroleum fuels in urban areas (the typical climbing up on the "energy ladder"[38] in developing countries).

Compared to the average world wide per capita biomass consumption between 1994 and 2005 of 1.9 kg (average population of 6 billion people and a total annual biomass consumption of ~ 50.7 EJ[39], with an assumed mixed traditional fuel energy value of 12 MJ/kg), Nepal still has a 42 % higher biomass per capita consumption of 2.7 kg per year (25 million people and 12 MJ/kg).

During the same time period there has been an almost five fold growth in the consumption of non-renewable petroleum energy resources, mostly for the transport sector. With 57%, or 183,402, of all of Nepal's registered vehicles in 2001 being in use in the Kathmandu valley[40], it is clear why Kathmandu suffers from serious air pollution problems. Also the massive increase in coal consumption, in particular from 1999 to 2000, with an almost four fold increase, indicates that the industrial use of heat energy (especially for the brick kiln industry) is sharply increasing.

Electricity consumption, though almost exclusively generated with hydro power in Nepal, increased almost 3 times over the monitoring period, with an average annual increase of ~ 10%. While that indicates an infrastructural challenge to meet such a demand growth, the amount of electricity consumed in the whole energy mix was still only 1.47 % of the total in 2002.

The energy services generated through renewables (not including any solar energy services), show a widely fluctuating picture year by year with growth rates between 10% - 30%, and more than a ten fold overall increase during the recording period. But the actual energy generated by renewables is still very low, and contributes less than 0.5 % of the whole energy generation mix.

The high rate of growth in energy consumption indicates the need for clearly defined long-term energy policies, which take the unique and fragile Himalayan ecology into consideration. These policies must be sensitive to the delicate environment, allowing people to utilize the locally available renewable energy resources on a competitive basis with the non-renewable energy resources. That would allow Nepal to protect what can still be protected, and may help to restore to some extent what has already been harmed through the uncontrolled growth in consumption of fossil fuels and inefficient combustion processes.

3. Approaches for Improved Energy Services for the Poorest of the Poor in Nepal's Remote Himalayan Villages

As mentioned above, 80% - 85% of Nepal's 27.6 million people live in rural areas, and ~ 80%, or 22 million, still have no access to electricity. In the following chapters various approaches to improving the energy services, mostly for lighting purposes, for marginalized and disadvantaged mountain communities, are highlighted and discussed.

3.1. Grid Connection

Nepal's national grid (total length is 4,346 km) is designed, built and maintained by the government owned NEA, providing around 1 million customers with grid electricity. These consumers are mostly located in the few urban areas and highly populated flat, subtropical southern part of Nepal (see figure 5). The few existing grid extensions into the more rural areas are characterized by frequent overloading, poor reliability, high line losses and power theft. The lack of grid extensions is understandable in the context of Nepal, as they are usually very costly, long-term investments. Further, the remote and mountainous areas are not only a challenge from the technical and geological point of view, but are sparsely populated, with few consumers per square km, with low energy demands and low expected load growth. Consumers are charged a flat rate, if at all, which provides no incentive to conserve electricity.

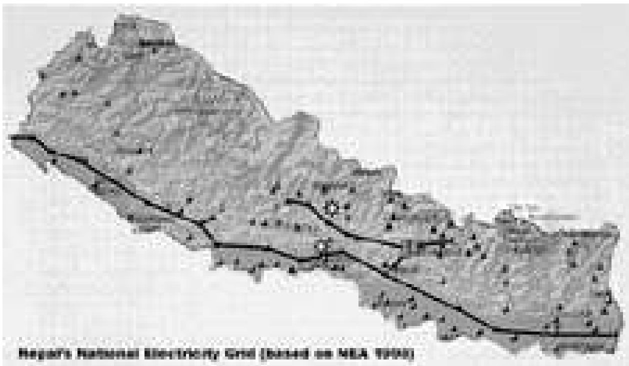


Figure 5: NEA’s existing national electricity grid, which is mostly connecting urban areas in the flat low altitude areas of Nepal.

Picture 4: Even though this resident had to provide land for transmission poles, it has not enabled the electrification of the home.

All of these conditions have placed great pressure on NEA, and the company has recently been restructured into three business units, the generation, transmission and distribution and customers services (retail)[41]. These units now aim to become profit-making businesses. Thus there is now even less hope for future rural electrification projects through NEA, which are non-profitable but serve the poor and remote mountain communities. Further, existing rural power generation plants are being sub-contracted either to interested private companies or to the communities themselves, to run them as local businesses. But most of the micro hydro power plants have been originally designed and built with the traditional approach “100 watts per household” for incandescent bulbs, making them too big and too costly for the local communities to maintain and repair.

3.2. RAPS Systems

Nepal’s unique geographical and topographical conditions demand new approaches and technologies in order to reach the 22 million people living in difficult and remote mountain areas without electricity. A viable option to grid extension is the generation of electricity within, or near to, a community, using locally available renewable energy resources. One solution that is growing in popularity is to generate the required power locally through a Remote Area Power Supply (RAPS) system. A RAPS system can be defined as a power generation system, generating electricity for rural homes and communities. Such systems are small scale (usually <50kWp) self-contained units, providing electricity independent of the main electricity grid or mini grid network. RAPS systems range from small petrol generators, able to power appliances directly, to more complex installations using either renewable energy only, or in combination with a diesel or petrol generators.

A RAPS system that has a combination of energy sources, such as a wind generator, solar panels, petrol or diesel generator, battery charge control system, battery storage and inverter, is called a hybrid RAPS system. For the remote mountain areas of Nepal a RAPS system will usually contain solar PV panels or wind generators. A petrol-powered back-up generator is not a feasible solution for the remote and impoverished mountain communities, as the transport cost for fossil fuels (carried by porters for days or weeks) is unrealistic. When the renewable energy resource is not available for prolonged periods of time, the way to ensure an appropriate back-up system is to design a battery bank, able to provide the required energy for a realistic span of time.

RAPS systems are often designed with 20 years life expectancy, and it is good engineering practice to include in the life cycle cost all the necessary operational, maintenance, repair and spare parts costs. This provides a realistic energy unit (kWh) price that each consumer has to pay, in order to keep the RAPS system operational. The locally available energy resources, the community's average daily energy service demands (including a realistic future load demand growth) and their affordable budget will determine the kind and size of the RAPS system.

Nepal's rich resources in hydro power and sunshine can be utilized locally through appropriate renewable energy technologies such as micro-hydro (5 kW – 100 kW) and pico hydro (0.1 kW – 5 kW) power plants[42], or solar photovoltaic modules and arrays, to generate the desired electrical power to meet basic energy demands. RAPS systems can provide a realistic and appropriate solution for the vast majority of Nepal's population still without access to electricity according to a community's identified needs and financial capability within their foreseeable lifetime. Further, often it is the community that owns a RAPS system. Thus in order to have strong ownership for the RAPS system, the community has to participate actively in each project step. That starts with the initial planning (defining and setting all the parameters of a RAPS system) and designing stage, the building and installation of the RAPS system, as well as operating and maintaining it. Local people are trained in the basic theory and on the job in all practical installation and operating work, assuring a high degree of ownership and thus willingness to maintain and repair the RAPS system. With such an approach and implementation, a RAPS system can provide basic electricity demands, which are often limited to elementary lighting, for even the most remote communities in appropriate and sustainable ways for years to come.

3.3. Elementary Rural Village Electrification

One of the first questions to ask for any village electrification system design is: "What is the most important energy service demand of a family in a remote mountain village?" And most of the time in remote villages the answer is: Light. In order to design an appropriate electrification solution for lighting purposes, it is important to understand the methods and technology people have thus far used to fulfill their lighting needs.

For example in the high altitude areas in Humla, in order to provide light in the otherwise-dark homes (as most have only very small unglazed windows which are mostly closed due to the cold), every home creates light inside their home by burning the traditional "jharro", a stick of resin soaked pine wood (Picture 5). They cook with firewood on an open fire, with either three stones, or a three-legged metal piece, called an "odhan" (Picture 6). Needless to say that the open fireplace and the "jharro", burning all evening, create very unhealthy living conditions.

Picture 5: Open fire place cooking and "jharro" burning. The traditional way of having a small dim light inside the home is the “jharro” (resin soaked pine wood stick burning to the left, with a one evening ration ready to be burned at the bottom left). Burning “jharro” emits thick black smoke which adds to the already unhealthy conditions created by open fire place cooking

Picture 6: Open fire place cooking is the traditional and common way to cook the daily food. The mother, and often the children, sit around the smoky fire as the meals are prepared. Women and children are most likely to suffer from exposure to the indoor smoke pollution[43], causing health hazards such as respiratory diseases, asthma, blindness and heart disease[44].

In this context, what options are available other than the smoky “jharro” for providing light for each home, light that is necessary for cooking, evening gatherings and children’s study times?

Behind most of the remote micro-hydro power plant projects is a financially strong and dedicated sponsor, without which such projects would not be able to take place. The bulky equipment for a 10 kW or larger micro hydro power plant weighs several thousand kilograms. Once installed, experience shows that it is almost impossible to dismantle it, when it is in need of repair due to failure. The technical expertise is not available in the village and the high transport cost for porters and air freight are prohibitive for most of the poor mountain communities[45]. These issues raise serious questions of appropriateness and sustainability of this otherwise widely approved and acknowledged technology.

But what kind of electrification technology and system is appropriate where the local people have identified home lighting as their most urgent need? Considering the local community’s needs, demands and financial capability (most of them are below the poverty line), a basic lighting system, that is affordable and reliable, is what they need. In order to provide a possible solution for lighting in this context, it is important to start improvements at both ends, the power generation and the light power consumption. If less power is needed for the lights, less power needs to be generated. Smaller systems are a lower financial burden for the local community, and thus more affordable without an external sponsor. Further, they are normally easier to build, operate, maintain and especially to repair, if they fail. They can also be designed in closer partnership with the local community, making them the proud owner of the system. Such a system is called an elementary village electrification system.

3.4. Appropriate Lighting Technologies

In most homes, which are powered by a micro-hydro power plant, and sometimes even by a solar PV system, in the rural mountain areas of Nepal, 2 - 3 incandescent bulbs, each 25 - 60 Watt, are installed. Thus a village with 50 homes needs a 10 kW micro-hydro power plant. The local people do not know any other lighting technology, thus they never questioned its appropriateness. An incandescent bulb has a life span of 750 - 1,000 hours. They are easy breakable, and to get a new bulb in the remote mountain areas is difficult, time consuming and expensive. Every single light bulb has to be flown in by airplane, and then carried by porters to the main bazaar, before one can purchase one at an exorbitant price. If a high quality CFL (compact fluorescent light) bulb, with a high Power Factor (PF) of > 0.9 is used (Picture 7), which consumes 7 – 11 watt (and is comparable with a 35 – 55 watt incandescent bulb with respect to its light output), the power generation can be 5 times smaller for the same amount of homes and lights. Further, CFL lamps have life expectancies of 8,000 – 12,000 hours. Thus, a 2 kW pico hydro power plant would be enough to provide the same lighting services for the same village.

Even less power needs to be generated if 1 watt white light emitting diode (WLED) lights, as shown in Picture 8, are used. Further, the expected life time of WLEDs is between 50,000 – 100,000 hours according to the manufacturers. But in comparison to good quality CFL lamps, with around 80 lumens / watt, WLEDs are still 50% - 100% lower in their lumens / watt rating.

While the future prospects for increased light output of WLEDs looks very promising[46], some of the best WLEDs (as e.g. the Nichia NSPW 510BS with a 50° light angle), produce only 26 lumens / watt. However, we have already some of the latest WLEDs under testing (Nichia NSPW 500CS with a 20° light angle), which have been rated by the manufacturer to produce 56 lumens / watt. While still more WLED lamps have to be installed in order to match a CFL lamp's light output, the power generation can though be reduced by a factor five – ten for the same level of service.

Picture 7: High quality CFL Lamp 11 watt (from Ultralamp), with a high Power Factor (PF) of >0.9, and with a life expectancy of 8,000 – 12,000 hours. Its light output can be compared with a 55 watt incandescent bulb.


Picture 8: Nichia NSPW 510BS (9 diodes with a 50° light angle) WLED lamp, consuming 1 watt, with a life expectancy of > 50,000 hours

Our aim was to design an elementary rural village electrification system for lighting purposes for the poorest and most remote mountain communities in Nepal. It is obvious that WLED lamps are the most appropriate and sustainable solution to fulfill the local people’s identified demands for minimal lighting. Their high availability (light emitting diodes are almost unbreakable compared to incandescent and CFL lamps) and sustainability (with an extreme life expectancy of >20 years), makes them very suitable for such projects.

4. Technologies Appropriate for Improved Energy Services in Nepal’s Remote Himalayan Villages

With the identified and estimated renewable energy resources in chapter 2.1. and the approach needed to reach remote and impoverished mountain villages and communities with an elementary rural village electrification project discussed in chapter 3.3. and the most appropriate and sustainable lighting technology for the context evaluated in 3.4., the base is laid to choose the right renewable energy technology.

Among the various available renewable energy technologies, very small hydro power plants, solar PV systems and small scale wind turbines, seem to be the most applicable technologies. It is important in order to increase the possible success of a project, that the most appropriate and sustainable technology for a defined context is chosen. This leads to initial questions such as:

- Is the technology chosen based on: Least-Cost, Preferred by the Community, Sustainable?
- Has sustainability been considered before efficiency?
- Can the power system be technically, economically, socially and environmentally sustainable?
- Can the consumer afford the energy services over the life cycle time of the system?
- Can the end users participate in all steps of the projects and can they be trained to operate and maintain them?
- Is the technology also culturally appropriate and acceptable to the end users?
- Can needed spare parts be made available from the local/national market in due time and for an affordable price?
- Can all stakeholders’ (end users, project implementer, donor) expectations be met?
- Can new activities and possible income generation projects be an outcome?
- Can the overall living conditions of the villagers be improved?

These questions have to be asked and answered satisfactorily by all stakeholders of a project. This is time consuming, with often additional costs, which are hard to justify.

In the following we will look into the three major applicable and locally available renewable energy technologies for Nepal’s remote mountain villages, hydro power, solar PV systems and small scale wind turbines.

4.1. Hydro Power Plants

With Nepal's vast hydro power potential of 42,130 MW, it is obvious that this technology is the one to consider first. The hydro power industry in Nepal distinguishes between large scale (≥ 10 MW), medium scale (≥ 1MW ≤ 10 MW), small scale (≥ 100 kW ≤ 1 MW), micro hydro (≥ 5 kW ≤ 100 kW), and pico hydro (≤5 kW). As the context of our study is small scale power generation, for basic lighting services only, this paper's analysis is limited to pico hydro power plants.

4.1.1. Pico Hydro Power Plant and Case Studies

As the name indicates, pico hydro power plants intend to generate miniscule amounts of power from a small stream or river. The actual amount of power generated is $\leq$ 5 kW, and they are mainly intended as power generation plants for remote villages which have identified their energy service demands as basic lighting, as part of their first exposure to electricity.

Thus in Nepal in the mid 90's NHE (Nepal Hydro Electricity) developed, with input and field test results from the main author, the first pico hydro power plant, generating 200 watts. It was mandatory that only material and equipment that is available, or could be manufactured, in Nepal was used in making this plant The principle of using a motor as a generator, according to the famous book "Motors as Generators for Micro-Hydro Power", by Nigel Smith[47], was the basic approach, as small induction motors are these days widely and cheaply available in Nepal. Using a motor as a generator achieves not the highest efficiencies, but it is an appropriate technical solution for the context in which they will be used. The technology is easy to understand, operate and maintain, and rough enough to survive the harsh and difficult conditions under which they have to work for years, with a low failure rate.

A first 200 watt (though in the field only producing initially 165 watt) pico hydro power propeller turbine, was installed in the village of Thalpi, in the remote Jumla district of north-western Nepal in 1997, followed by the second in the neighboring village of Godhigaun in 1998. The pico hydro power plant is designed with a low negative head, and uses 25 liters of water per second. The negative head means, that the pico hydro plant has a conical shaft of 8° after the propeller turbine. That shaft is 2.1 meters long, and can be installed in between the farmers' terraced fields, which are frequently watered. In this way no additional water to run the pico hydro power plant needs to be diverted from the fields. As each pico power plant is in itself a contained unit, it is easy to add further plants in series if the energy demand of the end users increases. For the Thalpi village a total of 30 households (with a total of 245 people) and three WLED lamps (each consuming 1 watt) for each household were installed. There was no detailed life cycle cost analysis carried out (as most of the local materials used have no trade value and thus would need to be estimated first). But every household pays 15 NRp (Nepali Rupees, which is 20 cents US $ (spring 2006), towards the maintenance, security and repair costs, to make the systems sustainable.

It has become customary that all the transmission cables (armored cables) are buried underground, despite of the substantially increased cost. This is justified because of the enormous amount of forest degradation in Nepal's high altitude Himalayan areas, and thus no further trees for transmission poles have to be cut throughout the lifetime of the power plant. Further, underground cables are protected from the often harsh weather conditions, such as snow, torrential rains, storms and lightning.

In both the following case studies from the first two pico hydro power plant installations in the Jumla district (see pictures), no cement has been used either for the power houses or for the water canals, which get their water from diverted small streams.

Picture 9: The Thalpi village people built the whole power house and stone/wood water canal, as part of their project input, thus being rightly proud of their pico hydro plant.

Picture 10: The power house, and the water canal of the Godhigau village 165 watt pico hydro power plant are built with local wood, with no cement which is prohibitive expensive.

Picture 11: Pico hydro power plant generating 165 watt

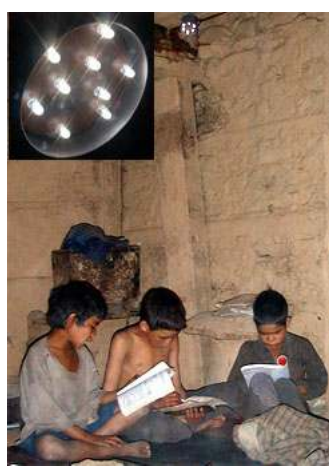
Picture 12: Wooden water canal of the Godhigau pico.

Picture 13: Installation of the Thalpi pico in the wooden canal

Picture 14: First test if light can be generated. What a life experience!

Picture 15: Even under

Picture 16: Now there is



Picture 17: Besides

Picture 18: The

harsh climate condition (down to - 20° C) the pico was performing well and flawless.	no need anymore to burn “jharro” to have a small light inside the home, and the air is clean.	socializing, basic literacy education is a major part to increase the people’s awareness.	young ones grow now up with light inside their homes.

In each village several people, chosen by the village pico hydro power plant committee, have been trained to operate and maintain the pico power plants, and to inform the project implementer of problems they can not handle. One of them is also a watch man, responsible for the security of the power plant. He is paid a small monthly salary from the fees collected each month from the users. Thus the pico hydro power plants are managed fully by the local village and the sense of ownership is high as they all have put a lot of hard work into carrying of the equipment, organizing all the local building materials, and building of the power plant.

The first 1.1 kW pico hydro power plant (with 80 liters of water a second, and 2.5 meter negative head, which gives an average efficiency of ~ 56%) is in the installation phase in a remote village called Kholsi in Humla. As the lights are usually on only for several hours in the morning and evening, the power plant has a low load factor. As this village has a high altitude climate, they are always in need of warm/hot water. Thus a “water heating dump” load was designed for any overproduction (full power during the nights and days), to a 500 liter hot water polyethylene storage tank, well insulated with locally available materials. Thus the community has access to warm water for washing and in the morning when they start cooking their rice. In this way again more fire wood for cooking can be saved, additional to the savings already achieved (on an average ~ 40% if properly used) through the improved smokeless metal stove (pictures 39 & 42).

What are some of the advantages and disadvantages of a pico hydro power plant?

Advantages:

- It is a locally available and maintainable technology, cheap to run and easy to operate.
- It runs under harsh and low maintenance conditions.
- The generator is so small that it can be carried by only one person.
- Several pico hydro power plants can be installed in series once the power demand grows.
- No cement is needed for the construction of the power house and water canals, as carrying it by air plane and then by porter to the high altitude area, increases the price ten times.
- The local end users can be involved in each project step, especially in the building phase, as they have to organize all the local materials such as wood, stones and mud.
- Through the intensive participation of the local community a strong sense of ownership is created, which is important for long-term sustainability.

Disadvantages:

- The technology (the induction motor and simple propeller blades) is not very efficient.
- It is designed for a “first time” rural village electrification, mainly for lighting purposes.
- The pico generators are induction motors, thus starting a motor could lead to difficulties in regard to severe voltage drop or even loss of excitation (but the pico power plants thus far installed are all exclusively only for lighting purpose).

4.2 Solar PV Systems

With an average solar irradiation of 4.8 – 6.0 kWh/m^2 (see 2.1.3.) for Nepal as a country, in the high altitude areas the solar radiation resource is in most places at the upper end of the scale, if the location is not extremely shaded from surrounding mountain ranges or in a deep valley. That highlights the importance of having exact and reliable data for the local prevailing conditions. Again, one of the crucial points for each solar PV village project is to use and install as much as possible locally available or locally manufactured equipment. That increases the appropriateness of the project, and helps the local industry to grow in a more independent way, creating new income for the society, as well as teaching new skills to craftsmen - all important parts of a holistic community development project.

It is important to underline, that any rural village electrification project is never implemented as an individual project, but as part of a much wider long-term holistic community development project in that particular village and area. Thus e.g. the elementary rural village electrification case studies described in the chapters 4.2.2. and 4.2.3. are each part of a holistic community development project including a smokeless metal stove and a pit latrine for each family, access to clean drinking water from various taps in the village, a greenhouse and a non-formal education (NFE) project for mothers and out of school children. In this way synergistic benefits occur and increase the overall positive development outcome for each village, family and person substantially beyond those of a single individually implemented project.

4.2.1. Solar PV Home Systems (SHS) and Case Study

The most straightforward approach is to install a small scale solar PV system for each single home, called a solar home system, or SHS. This was also in the mind of the policy makers for the solar PV home system subsidy program as mentioned in chapter 2.1.3. On each house one solar PV module, mostly between 20 – 40 watt rated power output is installed, with up to three 10 – 20 watt fluorescent tubes. Each system has a solar deep cycle battery of 40 – 75 Ah capacity and a simple charge and discharge controller, to protect the battery from too high discharge and charging rates. The price for such a SHS is high, around NRp 20,000 – 25,000 (~ US$ 278 – 347), and thus is not affordable by anyone in the remote areas without a subsidy.

There are now many cheaper SHS available on the growing SHS market, but their quality and performance is often questionable and thus they are not considered to be appropriate for remote areas (nor in fact anywhere else), and thus they are not considered further in this study. The SHS subsidy program created by the government's AEPC (Alternative Energy Promotion Center), started in 2001, and is defined as follows (http://www.aepcnepal.org/sp/se.php)

1. Subsidy will be provided to SHS of 10 W_R, 20 W_R and 30 W_R or more.
2. The maximum subsidy for SHS of 30W_R capacity or more will be NRp 8,000 per system.
3. Additional 50% and 2.5% subsidy per SHS system will be provided to the users in remote village development committees (VDC).
4. The level of subsidy will be reduced each year at the rate of 10%.
5. The subsidy for SHS used by public institutions such as the VDC buildings, school, Club, Health, post/ Centre etc. will be as high as of 75% of the cost.

Poor families will not have the economic capability to purchase a SHS once the subsidy has run for a few years, as the purchase cost is too high, and there is no substantial cost decrease in the foreseeable future for solar PV equipment. Further there is no clear follow-up program in place despite the requirement that the installers' are paid the last 10% of the total subsidy only after the SHS has been running for one year. That is not enough of an incentive to provide the end users with appropriate quality equipment which will last far longer. Thus most of the installers do not really count on the last 10% and there is very little forethought to how the installed SHS can be followed up and maintained beyond that one year time period.

Therefore it is recommended that SHS projects should be run as part of a long-term holistic community development project, with the end users as active partners (participating through their voluntary work as well as some financial contribution) together with the implementer (who works on a long-term basis in that area) and the donor agency (who provides the main project funding according to an agreed project proposal and budget). The following pictures show SHS implemented in Khaladig village in Jumla, as part of a holistic community development project.


Picture 19: The first step is always to raise awareness in the community and to inquire and define what their needs for energy services are.

Picture 20: Transportation is one of the hard tasks.


Picture 21: Both genders have to be involved equally.

Picture 22: On the job training through hands on installation


Picture 23: Teaching and learning go hand in hand


Picture 24: One 40 watt solar PV module for 3 lights

Picture 25: 20 watt fluorescent tube

Picture 26: Training the end users to maintain and conduct basic repairs is crucial for sustainability of every solar energy project.

4.2.2 Village Cluster Solar PV System and case study

While SHS are a very appropriate technology to bring light into the homes of single homes in remote villages, we learned that an even better approach is to get the whole village motivated to apply as a community for an elementary rural village electrification project. That brings the dynamic, skills and work force of the whole village community into the project. Further, it creates a challenge and responsibility for each person of the village to participate in the project, thus including the poorest, marginalized and handicapped. The common planning, designing and building of the village power system creates a strong sense of community project ownership.

Over the years, two approaches, the village cluster solar PV system and the village central solar PV system have been developed in order to electrify a whole village. Which of the two approaches is chosen depends mostly on the village's situation in regard to the positioning of the houses and the village's geographical position compared to the sun's path over the year.

The village cluster solar PV system defines individual clusters of up to 15 houses in such close proximity to each other, that all of them can be easily interconnected with each other through armored underground cables. The house in the middle is the cluster's power house with one BP 275F silicon monocrystalline solar PV module with 75 W_R on the flat mud rooftop. Further, one charge- and discharge-controller and an appropriately sized and well insulated battery bank are installed inside the house. Each house has three WLED lamps. Thus up to a maximum of 15 homes, with 45 WLED lamps are connected to one cluster, with 5-6 hours of light per day. Each cluster has a newly developed electronic fuse to protect the system from misuse and overloads. The following pictures show and explain the village cluster solar PV system in Dhadhaphaya village in Humla, installed as part of a holistic community development project from January 2005 on. Since September 2005, 18 clusters (with a total of 1,182 W_R installed solar PV modules)[48], for 170 homes (total 1,067 people), with 510 WLED lights are operational. Each day the trained local operators provide power from the cluster power houses to each cluster house for a total of up to 6 hours, 2-3 hours in the morning and 3-4 hours in the evening.

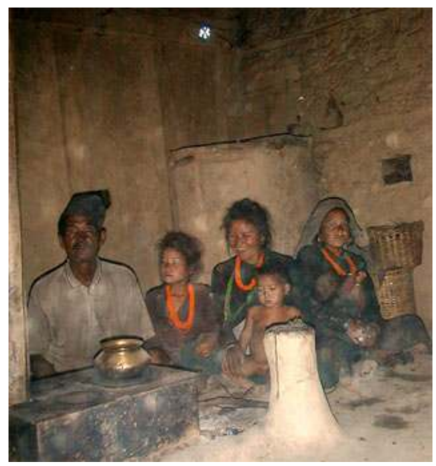
Picture 27: clusters, each with 8-15 homes connected

Picture 28: One 75 W_R module, adjustable to the season, fixed with stones

Picture 29: Cluster power house with charge controller and battery

Picture 30: Checking the battery and charger

Picture 31: Project staff and user install the solar PV systems together, creating knowledge, skills and ownership



Picture 32: 3 WLED lamps per household create clean indoor air.

4.2.3 Central Village Solar PV System and case study

If the geographical conditions are favorable and the houses are built closely together, the elementary village solar PV system can be built as a central system, with a central village power house containing the battery bank and the charge- and discharge-controller for the whole village. On top of the central power house a 2-axis self tracking frame, developed and built in Nepal, holds four 75 W_R solar PV modules, enough to power the whole village of Chauganphaya with 63 homes and each with 3 WLED lamps. In January 2004 this central village solar PV system was installed and has worked since without interruption. All 63 homes are interconnected with the power house in the shortest possible way via 50 – 80 cm deep buried underground armored cables. Three sizes of armored copper cables are used. 4mm^2 for distances over 20 m (maximum 50 m), 2.5 mm^2 for distances between 10 m – 20 m and 1.5 mm^2 for distances ≤ 10 m.

The whole system is protected with a central electronic fuse, so that any misuse or overloading of the system causes the immediate shut down of the system. The electronic fuse was developed because it is not possible, in such remote places, to get any glass fuses which are commonly used otherwise in solar PV systems. Experience shows that many SHS have failed because the charge controller glass fuse broke and the users either did not know that there was a fuse, as they were not trained to maintain the system, or they could not get a spare glass fuse in the local market. Some months later, when the battery has not been recharged it fails too and normally that's the end of the SHS and the dream of light inside the home.

Picture 33: In the middle of the village of Chauganphaya the local people have provided the land to build the central solar PV system power house. From the power house all homes are connected via armored underground cable, buried at a depth of 50 – 80 cm.

Picture 34: The local people built the power house with their own materials. It contains the battery bank, which provides up to 5 days power for all the lights during no-sun days, and a charge and load controller (pictures 37 & 38).

Picture 35: The north-south axis can be changed from 5° to 60°, according to the sun' seasonal position.

Picture 36: The tracker follows the daily sun path from east-west, and back in the morning to east, by itself.

Picture 37: Charge- / discharge-controller, with separate load controller, inside the power house.

Picture 38: The battery bank well insulated in a locally made wooden box.

Picture 39: The light project is never on its own. The metal stove is always part of it.

Picture 40: Total 189 WLED lamps in 63 homes are now installed in Chauganphaya.

Picture 41: Light

Picture 42: Smokeless Metal Stove

Picture 43: Pit Latrine

Picture 44: Pit Latrine

Picture 45: Greenhouse

Picture 46: Drinking water

In a holistic community development projects, light inside the home has to go along with a smokeless metal stove, a pit latrine, a greenhouse and clean drinking water, as above shown.

4.3. Small Scale Wind Generator System and Case Study

The utilization of wind energy through ever increasing sizes of wind generators and wind farms has become the major new renewable energy technology on the market. The wind technology and the manufacturing industry are mature and new development and creative designs are occurring at an amazing rate. Through wind farms, generated electricity has become highly competitive to the major fossil and nuclear power plants in many European countries. Nepal will not generate its major energy needs from large wind generators or wind farms in the foreseeable future. Rather, the valuable local wind resource of particular geographical places can be utilized for small scale applications, be it for single homes or rural villages.

In the following pictures a self made 2 bladed wind turbine is presented, which was installed in Jumla in 1998, as part of a first small scale wind test project. It ran, and provided power for one home for 4 years (picture 49). The wind turbine was installed in a valley in close proximity to the house. Therefore the predicted power output of 180 watt, was seldom reached. The aim of this project was to put to the test a self made wind turbine and to see if it can survive the harsh high altitude (≥ 2,500 meters above sea level) Himalayan wind conditions and climate. If so, there is a future potential for such wind turbines to be made out of local available wood for the blades.

The 18 m steel tower (Picture 51) was screwed together with three six meter long pieces of Ø 125 mm, Ø 100 mm, and Ø 75 mm from the bottom up. At heights of 9 meters and 16 meters, three steel cables (Ø 8 mm) were fixed to the pole and anchored to the ground, in order to stabilize and hold the tower firmly in place in any wind condition. The bottom of the steel tower was anchored in a big stone pile, without any cement. During the four years of operation the wind turbine performed satisfactorily. It did not need to be taken down once for repairs.

While there is still a long way to go in regard to technical issues such as: an improved and appropriate design for the blades (in order to manufacture them by hand by local craftsmen); and the right choice of the generator with a direct drive, encouraging results have been achieved. The test phase has shown that there are ample reasons to pursue the research and development for such small scale wind turbines, which can be manufactured and maintained by the local industry. They can provide one more appropriate and sustainable renewable energy technology to meet the needs of rural villages and communities, providing them with improved energy services for the overall development of their living conditions. The following pictures show the self made wind turbine with its different main parts, the installation and operation in Jumla.

Picture 47: Self made 2 bladed wooden wind turbine, wooden tail with metal frame, and a Bosch car alternator as power generator. The wooden blades are hand carved aerofoil shaped blades with a blade diameter of 205 cm. From ~ 300 Rpm onwards the wind generator provides 12 volts to charge the battery bank.

Picture 48: Bosch K1 14 volt 35 amps car alternator, 1:4 wheels with belt set system, capacitors, electronic circuit plate, brakes

Picture 49: The self made wind turbine charges a 12 VDC battery bank of 150 Ah capacity, enough for one home.

Picture 50: Power generation of maximum 180 watt can be achieved.

Picture 51: Wind turbine at 18 m height.

5. Towards a Theoretical Basis for a Holistic Community Development Projects

Since 1996, the main author has had the opportunity to live and work in the most remote and impoverished Himalayan villages in Nepal. After such a long time it becomes “obvious” that one acts, feels and thinks more and more like the local people. These experiences were crucial to achieving a deeper understanding of the “non-verbal” issues of a society and culture. Their needs and “wants” become more understandable and appreciated once we realize that the daily “comforts” most of us take for granted, such as having access to clean, immediate and sufficient electrical power at any time by the flick of a switch, are not a common commodity in the developing world. However electricity for lighting purpose is an important and consciously appreciated service in these remote villages.

One important outcome over the course of the past 10 years was the development of increasingly smaller scale renewable energy technology projects for elementary rural village electrification for lighting purposes, designed and implemented in close relationship with the local communities.

Another important result was the increased interest, positive response and willingness of the villagers to participate actively through hard work and some financial contributions. This gave a healthy push to expand the borders of the “common” approach to community development, which can be summarized in a nut shell as being mostly the implementation of single projects, with minimal presence in the village for short time spans, with minimal previous investigations and minimal or no follow-up program. Thus the focus no longer remained only on single families having light inside their dark, smoke filled room, but whole villages were addressed with the proposition to implement a joint village – project team elementary lighting project.

Further, any lighting project was no longer seen as an individual self-contained project, but as one part of a more holistic project, addressing people’s physical, social, mental and spiritual needs in their life. With this approach the benefits of each individual project increase, as it gains from the benefits of the other, simultaneously implemented projects. Synergetic benefits are created which can bring far more changes than single implemented projects.

Thus the concept of the holistic community development (HCD) project approach took shape. For example, the HCD 2006 Humla project, which started on the 1st January 2006 in two small villages, includes the following individual, equally important, parts[49]:

1. Smokeless Metal Stove and Indoor Pollution Monitoring and Data Recording Project
2. Pit Latrine Project
3. Elementary Solar Cluster PV Village Electrification Projects with WLED lights in one village for 35 households
4. Elementary Solar Tracking PV Village Electrification Projects with WLED lights in one village for 35 households
5. One Village Drinking Water System Project
6. Greenhouse and Solar Drier Project for two villages (as under point 3 & 4 mentioned)
7. Nutrition Project for < 5 years of age, malnourished children
8. NFE (Non-Formal-Education) Children Project
9. NFE Mothers Project with teaching topics developed about the HCD project.
10. Slow Sand Water Filter Project for clean drinking water for individual households
11. Baseline Survey Data Collection Project in the villages of Tulin and Pamlatum (point 3 & 4)
12. Re-survey Data Collection Project in the villages of Chauganphaya and Dhadhaphaya (these are the villages HCD projects have started in 2004 and 2005 respectively, and will continue for the next 10 years (political and funding conditions allowing) to be partnered with and followed up through periodical visits and annual re-survey questionnaires specially developed for a HCD project).
13. Humla Spring and Drinking Water Testing and Data Collection Project (in order to be able to identify the seasonal drinking water pollution and possible pollution sources, in order to design appropriate drinking water projects and source protection).
14. Follow-Up Program Project for all 2002 - 2005 Projects (through periodical visits to all installed smokeless metal stoves, pit latrines and lights, recording people’s experience and suggestions of improvements)

15. Humla Staff Training Project (in order to have an ongoing and continuing project staff education, in order to keep them interested, able to fulfill their job responsibility and updated with the important and new technical, administrative, cultural and educational skills needed for the HCD project implementation).
16. Humla Simikot Office Project (to keep the main office, the HARS (High Altitude Research Station) in Simikot Humla (picture 52) up and running as the base for the implementation of the HCD projects, as well as the testing and monitoring of the various new technologies developed for the HCD projects before they are implemented in the village, and to keep up the long-term solar radiation measurement and data recording).

As can be seen from the above list of projects, a HCD project, if taken seriously, is a complex and intertwined undertaking, which requires clear structural organization and guidance. In the case of the Humla projects it is a close partnership between the RIDS Nepal (Rural Integrated Development Services) NGO (Non Governmental Organization) some donor agencies (mainly *The ISIS Foundation* and LiN (Light in Nepal)) and the local communities and interest groups, which build the base for a long-term involvement in these villages.

Further, it can be seen that while the main part of the HCD Humla 2006 project is clearly in the implementation of projects in the villages, the RIDS Nepal project staff, who are all from the local vicinity, are also continually encouraged to be involved in building their capacity through further education programs. These could be a PC training, so that their planning and reporting becomes more aligned with international donor agencies, or it could be a more technical education through learning modules loaded on the PC (as there is no internet access available in Simikot Humla). Further, courses, such as nutrition or NFE course development and delivery are planned to be taken in other, more urban based, topic related, institutions. That allows an NGO such as RIDS Nepal to become more and more capable and able to carry the project responsibilities by themselves, with the idea that one day the HCD projects will be led and run by the local people only. And by that time they will be prepared and able to do the job with the necessary enthusiasm, as well as the essential professional skills.

To start a HCD project is not an easy and straightforward task, as it involves not only technical and organizational issues, but also the so called “soft issues”. These social and cultural matters, are often far more crucial and time consuming to address in culturally appropriate and sensitive ways. These are issues which are not easy to propose and “sell” to a donor, but are crucial for long-term sustainability and thus success for a HCD project, which aims to improve the living conditions of the local people in ways which respect them as equal partners.

6. Experience and Lessons Learned

To share in detail the experience of 10 intensive years of living and working with the marginalized mountain communities in the poorest area of Nepal, the north western district of Karnali, is an impossible undertaking for a paper like this. Further, to address the more detailed technical issues of each applied technology is beyond the scope of this paper and many of these aspects for solar PV systems have been addressed in another paper[50]. Thus, in the following comments, some more general points, experiences and lessons learned through the implemented HCD projects are listed, with the main focus on applied renewable energy technologies, to utilize the local available renewable energy resources mainly for lighting purpose.

- Any renewable energy technology project for lighting purposes should be an integrated part of a wider HCD project.
- A HCD project is much more time demanding than a mere implementation project, with a long-term (at least 10 years) vision and willingness to be involved in the village's life.
- It is highly advisable, if not essential, for the project staff to live in the village or in the nearby vicinity of the HCD project area. That enables them to learn the local people's customs, culture, thinking patterns and local technologies (that have often been developed over decades and centuries) These are crucial learning steps to enable a HCD project to start on the right track and to make it as appropriate as possible from the beginning.
- Each village context is unique and thus needs a clearly defined assessment, with the local people as the discussion partners. This must precede the technical planning of the project.
- The local people have to identify in qualitative and quantitative ways their own needs before any project plan and proposal for a renewable energy technology project is prepared.
- Identify the local most sustainable and available renewable energy resource, and then determine the appropriate technology accordingly.
- Develop and manufacture the equipment as much as possible from local resources and through local manufacturers and craftsmen. That improves the local economy in a sound way through income generation and teaching new skills and techniques. It also builds capacity for maintenance and further projects.
- As far as possible, use genuine parts and good quality products, as once the equipment is installed in the remote area, the failure rate should be minimal. Repairs are expensive and often impractical in remote locations.
- Include in each project proposal some funds for equipment development. This is a difficult and often not appreciated budget point by donors, but it is crucial to the implemented projects becoming more appropriate and thus sustainable. It is important to realize that there are no "off the shelf" solutions available for a particular village's self identified needs.
- Some funding should be devoted to reporting and monitoring of the project after installation so that experience gained can be documented and passed on to future designers.
- Engage as much as possible local people as project implementation staff. Take the necessary time and effort to train and educate them for their job responsibilities. It will pay off in the future, if local skilled professional people work in their own vicinity and neighborhood.
- Use as much as possible available local materials for project implementations.
- Always include theory, operating and maintenance training for the end users. Provide/create channels so that they can communicate with the project implementer for years to come if major technical, or social, problems occur.

It has been the author's experience, that research and new equipment development has to take place on an ongoing basis, in order to develop equipment which is locally manufactured. This equipment is generally easier to maintain, and hopefully can cope better with the local conditions and climate.


Picture 52: HARS in Simikot Humla at 30° northern latitude and 3,000 meter altitude.

To implement newly developed equipment and technologies is always a risk, thus in the case of the Humla HCD projects, the HARS (High Altitude Research Station) has been built (picture 52). At HARS all newly developed technologies intended for village use, are first monitored and tested, and if necessary they are improved (see e.g. the high altitude SWH for the Dhadhaphaya village, which is at the time of writing in its test phase at HARS as indicated in pictures 2 & 3). This quality assurance process will keep the failure rates and system downtimes in the villages to a minimum. Experience shows, that sustainability and appropriateness are key aspects of a project that must be addressed in order to deliver the intended energy services to the beneficiaries. That means we must keep the end-users at the centre of our focus and develop and install renewable energy technologies that can deliver what is expected by all stakeholders.

7. Conclusions

One of the main aims of this paper was to demonstrate to a wider readership of like minded professionals, HCD project implementer and renewable energy technology enthusiasts that appropriate solutions are available to make a difference to the 1.6. – 2 billion people still without any access to basic electrical services such as light inside their homes. Renewable energy resources are, unlike fossil fuels, far more equally distributed on the planet, and are more sustainable in the long-term. They may not have the energy intensity (MJ/kg) as conventional fuels and are not as easy to store and transport, but they are locally available, a great plus point.

Further, developing and increasing the access to renewable energy sources does not mean that we start harming the ecosystem, as has clearly happened with excessive fossil fuel consumption. It means that mankind has to come back to its “roots”, asking where do we come from, why are we here on earth and where are we going? As to utilize renewable energy resources, in particular on a small scale, means to work in tandem alongside the creator’s handiwork, putting it to good use for our personal and society’s holistic development. We must understand that it is not for us to dictate the speed and ratio of extraction of an energy resource, and thus forget all the peripheral and even more the negative synergetic effects of being “out of harmony” with the creation. We must also realize that over-exploitation of renewable resources such as wood and water can be just as damaging as the over-use of fossil fuels. We have to come to an understanding of what is available in renewable and sustainable ways and forms, and how it can be put to our best and most efficient use. We have to re-think what are our “real” needs rather than just our “wants”, which too often are not really needs but expressions of our greed.

Often we would not even need to step back and “un-develop” ourselves if we switched our thinking from the use of fossil fuel resources to the use of locally available renewable energy resources according to their availability and intermittency. We would need to become creative and use our engineering skills and tools to make the most out of what is available. Thus efficient use of energy, energy savings, new low power consuming energy technologies, energy storage and energy conversion technologies and devices should be issues at the forefront of each motivated and humane engineer. With the pico hydro systems, various different kinds of solar PV systems, solar thermal technologies and project approaches presented in this paper, appropriate technical solutions to improve the livelihood of millions of disadvantaged people have been shown and discussed. It is not possible in the scope of this paper to be comprehensive and address all the technical issues of each renewable energy technology mentioned. Rather it tried to show possible paths and approaches, which should stimulate others to join, to start and to put into action new contextualized technologies for their own situations. This will ensure that more needy people can be reached in a more appropriate way and timeframe than we have been able previously. That is part of our common responsibility towards our society.

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10. Authors' Biography

Zahnd Alex has a mechanical engineering degree from Switzerland, and a Masters in Renewable Energy from Australia. His industrial experience ranges from development projects in extrusion technology for the food and plastic industry, to pharmaceutical production plants. He lived and worked from 1996 - 2000 in one of the remotest and poorest mountain communities in the Nepal Himalayas, in Jumla, as director of a holistic community development project. Since 2001 he has been a member of expatriate staff of Kathmandu University, mainly involved in applied research of renewable energy technologies, with implementation on a village scale in the remote mountain districts of Humla and Jumla. He is currently working on his PhD in rural village electrification systems for Himalayan villages.

Dr. Haddix McKay, Kimber is a cultural anthropologist who specializes in demography, health and human behavioral ecology. Dr. Haddix McKay has worked both full time and as a consulting anthropologist designing studies of health and treatment of illness in remote areas of Nepal and Uganda. She has lived and worked in Nepal frequently from 1994 to the present, and assisted in the design of locally appropriate development schemes aimed at improving health conditions, particularly in the use of sustainable energy technologies and in public health-related interventions such as latrine design, improved/smokeless cooking stoves, lighting schemes, community based health training, and drama programs with specific health-related messages.

Dr. Richard Komp, is the author of PRACTICAL PHOTOVOLTAICS and has been working on solar cells since 1960. He has taught numerous courses and workshops on solar energy all over the world; is president of the Maine Solar Energy association, has a small photovoltaic company, Sun Watt Corporation, and teaches graduate courses on Solar Energy at the Universidad Nacional de Ingenieria in Nicaragua.